The Association
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Draughtsmen.

MAGNETISM IN INDUSTRY AND SCIENCE.

By H. E. HUTTER.

Published by The Draughtsman Publishing Co., Ltd.,
Mansefield," Market Street, Rugeley, Staffordshire.

SESSION 1942-43.

Milne, Tannahill & Methven, Ltd. (T.U.), 12-14 Mill Street, Perth.

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MAGNETISM IN INDUSTRY AND SCIENCE.

By H. E. Hutter

INTRODUCTION

The everyday applications of Magnetism, such as dynamos, motors, brakes and compasses, are familiar to all engineers, but not many are acquainted with its many other applications to industrial and scientific work.

The handling of scrap and pig iron is greatly facilitated by the use of lifting magnets. Foundries rely on the magnetic separator for the reclamation of sand. Machines operating on definite time cycles employ automatically-controlled magnetic clutches, while for cranes and lifts the magnetic brake is essential.

The ship's navigator relies on the magnetic sounding apparatus under difficult weather conditions, engineering works check components for flaws with the aid of magnetic crack-detecting apparatus, and the designer employing ferrous materials under conditions of high-alternating stress, obtains quick reports on fatigue strength with the aid of the magnetic tester.

The scientist employs the largest magnets for atom-smashing experiments, or possibly an investigation into cosmic rays, while other uses of magnetism range from exploding magnetic mines to children's toys.

It will be noted that the subject covers an extremely wide range and in the restricted space available it is only possible to touch on a few general items, but it is hoped that some idea of the interesting applications of magnetism will have been given.

Various theories are expounded regarding the nature of magnetism, but they cannot be considered here due to space limitation, and the reader is referred to the bibliography.

Materials, from the magnetic point of view, are divided into three groups. Firstly, there are ferromagnetic materials, which can be magnetised to a high degree, examples being, iron, nickel, cobalt and Heuslers alloy, the latter consisting of aluminium, manganese and copper and having a magnetic permeability one-third that of the purest iron.

Paramagnetic materials are those which can be magnetised to a very much lower degree, examples being chromium, manganese, crown glass and liquid oxygen. The last group covers materials classed as diamagnetic ; that is, having a permeability lower than 1, and which are repelled by a magnet in air. Examples are arsenic, flint glass, antimony and alcohol.

The magnetisation of a material results in a number of phenomena, some of which are utilised ; for instance, bismuth has the property of changing its resistance when placed in a magnetic field ; a calibrated coil, in conjunction with a resistance bridge, forms a convenient method for measuring field strengths.

Magneto-striction is the effect experienced whereby a body changes its length when magnetised ; this property is employed, for example, in the echo-sounding device for measuring the depth of the sea. Other effects include the Hall effect, producing a difference of potential between two edges of a conductor-carrying current in a magnetic field. The Nernst and Ettinghausen effects are closely related to this.

Other effects more closely allied to optics are the Zeeman, Faraday and the Kerr effects, the last two referring to the rotation of a beam of polarised light in a magnetic field.

A further effect is the magnetocaloric effect. Briefly, the effect of this is, that if a ferromagnetic is placed suddenly into a strong magnetic field the temperature of the ferromagnetic will rise, and similarly, on suddenly removing it from a strong field, the temperature will drop. This effect is used in producing extremely low temperatures. A small amount of a paramagnetic is enclosed in a special vessel and the temperature brought down to 1·6 deg. K by reducing the pressure above liquid helium. The magnet is then switched on, and after a few seconds, switched off. The temperature will then fall as low as ·19 deg. K. At these low temperatures, the phenomena of super-conductivity can be demonstrated.

To those readers who are unaware of super-conductivity, it may be mentioned that under these conditions a current which is caused to flow in a coil, started by the insertion of a magnet, may flow for many hours without any further assistance.

MAGNETIC CLUTCHES

The magnetic clutch is probably familiar to most engineers, the major advantage claimed over other types of friction clutch being the ease with which it may be controlled, either manually, by means of a small hand-switch, or automatically, by means of time clocks, limit switches, unloader valves, etc., without the intervention of long operating rods which may have backlash caused by wear, or other mechanical linkage.

An inherent electrical feature is that the time taken for the clutch to engage is always the same, but can be varied by suitable electrical control gear. No adjustments are required until the friction lining has worn down by a considerable amount.

A typical magnetic clutch is shown in Fig. 1, and consists essentially of two parts. One part, keyed to the driving shaft, comprises the main magnet body carrying the magnetising coil and slip rings for conveying the current to the rotating coil. The other half of the clutch consists of an armature slidably mounted on a hub keyed to the driven shaft and carrying springs to throw off the armature when the clutch is disengaged. The friction lining may be mounted on either half, according to the design.

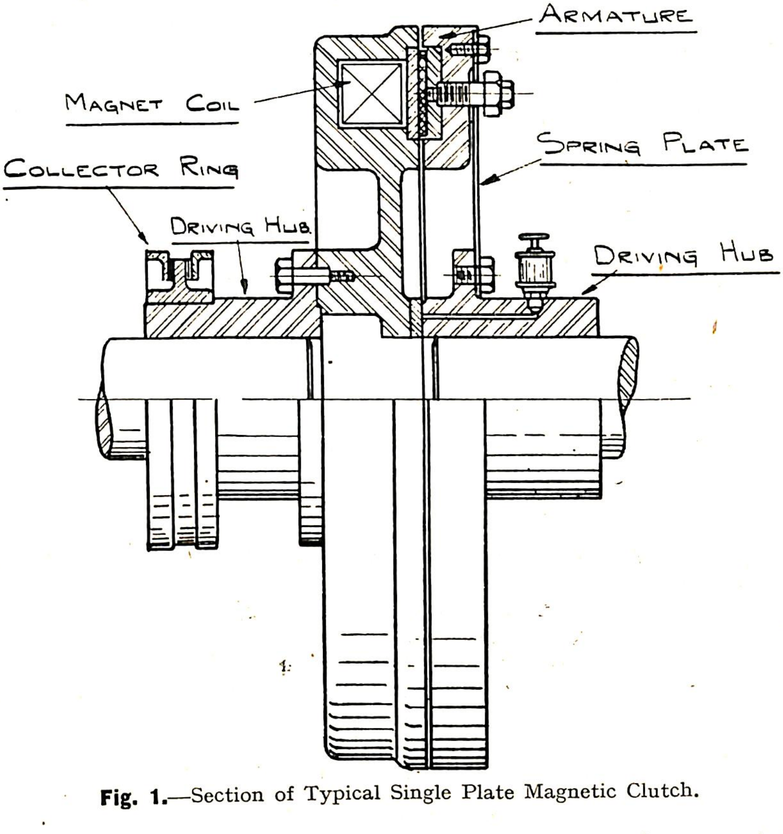

Fig. 1.—Section of Typical Single Plate Magnetic Clutch.

The driving power of the clutch is obtained by the magnetic attraction of the body against the armature and thus gripping the friction linings. This pull rises to a very high value, and in the larger clutches mentioned below exceeds 22 tons. The actual pull is calculated as follows :—

$$\text{Torque} = \frac{\text{H.P.} \times 5280}{\text{R.P.M.}} \text{ ft. lbs.}$$

$$\text{Pressure} = \frac{\text{Torque}}{\text{Mean radius} \times \text{coefficient of friction of lining}} \text{ lbs.}$$

Magnetic clutches of many other types are made for special applications. The multiplate clutch, with its greatly increased lining area, permits gradual starts to be made for machines having very high inertia.

The toothed type of coupling has teeth cut in the armature and body which engage together in place of a friction lining. This type has a limited application, such as rolling mill screw-down gears, where the positive drive keeps the screws in step, but allows individual adjustments to be made to the screws when the clutch is disengaged.

The magnetic clutch can be employed as a slipping clutch on the lines of the spring-controlled unit, with the difference that the unit can be automatically disconnected by thermostats when the linings reach a predetermined temperature. Large clutches of this type have been designed by the writer. Two sets were mounted between 550 H.P. Diesel engines and large pumps on a dredger; the bore of the pumps was such that the logs, ropes and large stones could be sucked up and jam the pump. Should a jam occur, the clutch was automatically disconnected and visual indication given on the bridge.

A further set of special design was used for connecting 1600 H.P. motors to the racks of tube-push benches, the overload capacity of the motors being so high that the bench would have been wrecked should a jam occur. The couplings were, therefore, designed to slip at 30,000 ft. lbs. torque. The couplings weighed 2½ tons each, had a rim speed of 95 M.P.H. and accelerated from rest to 500 R.P.M. in 2·2 seconds.

ELECTROMAGNETIC SLIP COUPLINGS

The slip coupling is of a radically different design to all other couplings, as there is no mechanical connection between the two halves of the coupling; it was first employed in connection with Diesel-engined ships. The use of high-speed engines in pairs driving a single-propellor through gearing called for a coupling to enable a single engine to be disconnected. The hydraulic coupling enabled this to be done, but had the objectional features of high cost and great weight.

The advantages of the slip coupling are—much lower weight, lower first cost, and elimination of all torsional vibrations; instantly

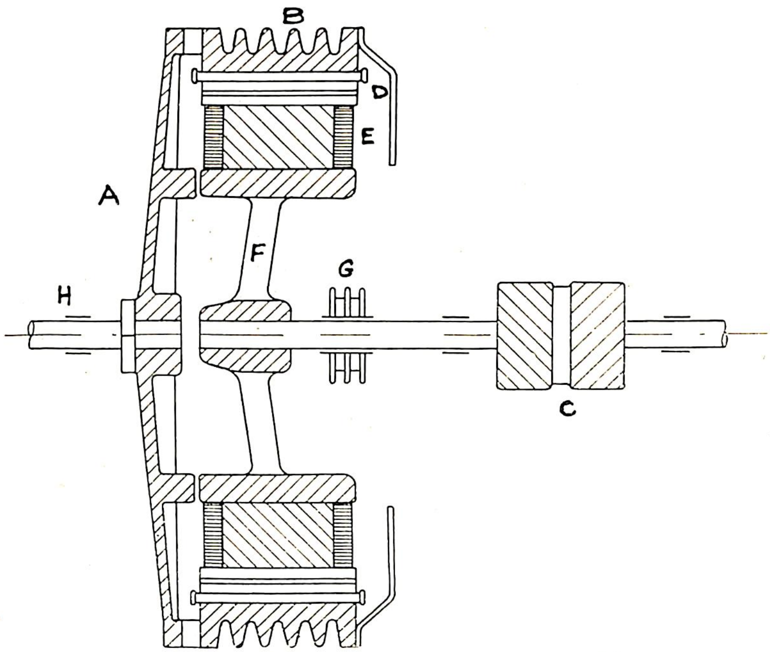

Fig. 2.—Section of Electromagnetic Slip Coupling.

reversible and disconnected ; controlled by a small switch and it also acts as a flexible coupling to take up misalignment.

The principle on which it operates is illustrated in Fig. 2. The coupling consists of an inner multipolar magnet ring, excited through slip rings by D.C. current and coupled to the gear shaft. The outer part of the coupling carries a ring provided with a short-circuited winding forming the secondary. The coupling parts overhang their respective shafts and are not interconnected mechanically, though provision is made for this in case of failure of the electric supply.

The operation is as follows :—A magnetic field is produced when the primary coils are excited, and this cuts the secondary winding, which is in the form of a short-circuited squirrel cage winding of bare copper bars. Even at small relative differences of speed between the two coupling sections, heavy currents are induced in the secondary which produce resistance to this relative motion. The transmission of power is effected by this resistance to motion.

The application of a load to the coupling results in an increase in slip between the two halves, heavier currents are induced, and the resistance to motion, and thus the torque transmitting capacity,

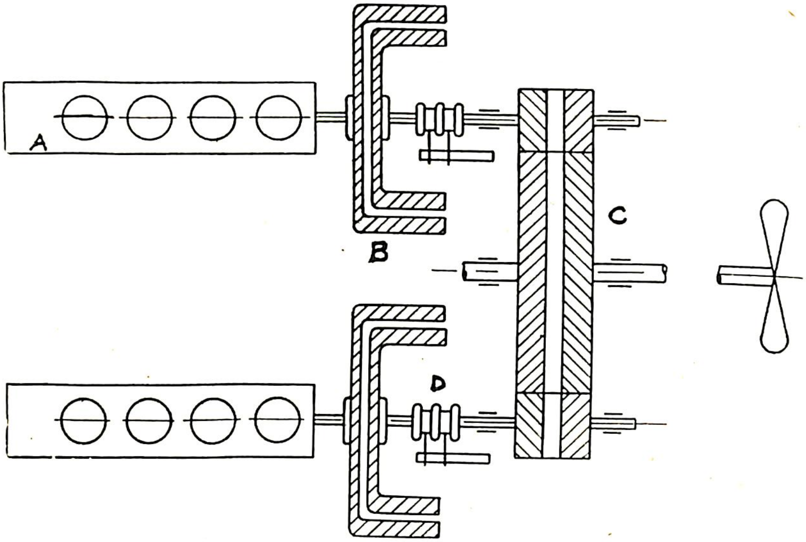

Fig. 3.—Layout of Duplicate Engines with Electromagnetic Slip Couplings and Reduction Gear.

are increased. The torque thus depends on the slip, which at normal full load is of the order of 1·5%, the torque rising to 220% of normal at 6% slip. At increased slip the torque decreases until at 100% slip—that is when the engine is running at full speed and the propellor is stationary—the torque is 25% of normal.

The efficiency is high, of the order of 98%, the only loss being in the excitation winding, which is dissipated as heat.

MAGNETIC ORE SEPARATORS

The magnetic ore separator is a most interesting application of magnetism, due to the need, in many cases, for magnetic fields of high intensity to obtain satisfactory operation.

The commercial magnetic separation of ores dates previous to 1900 and is still widely employed, despite the great advance in chemical and mechanical means of separating and concentrating. The first practical applications were to the separation of strongly magnetic iron ores, such as magnetite, from gangue or some other mineral less magnetic.

The development of the separator and the design of machines employing high field strengths led to their employment in the separation of minerals of feebly magnetic nature.

A large number of materials may be termed magnetic, though their magnetic susceptibility, the most useful means of comparison, is extremely low for the majority. Unfortunately, reliable information on this point is not available, though much information has been published, the tests not having been carried out in a uniform manner.

Data relative to some materials is listed below in comparison with iron ; all are, however, not commercially separated. Materials which are regularly separated include magnetite, monazite, tantilite, ilmenite, wolfram, corundum, stained (iron) particles from silica, and fireclay. The separation is carried out to purify the product, as for example, the removal of iron-stained particles from silica sand required for optical glass, or the concentration of a mineral from its associated constituents.

Relative Magnetic Attractive Force of Various Minerals.
Iron = 100.

Magnetite,	40	Franklinite,	35
Ilmenite,	24	Siderite,	1·8
Zircon,	1	Garnet,	·4
Quartz,	·37	Rutile,	·37
Zinicite,	·1	Galena,	·04

A typical concentrating separation, which is regularly carried out commercially, is the selective separation at one pass of monazite sands. These are of variable composition, depending on the part of the world from which they have been obtained. The minerals usually contained in the sands are magnetite, ilmenite, garnet, zircon and monazite. The magnetite is highly magnetic and can be easily removed by a drum separator, as mentioned in the section on Magnetic Separators. The susceptibility of the other minerals varies only slightly from each other and they are separated by close regulation of the magnetic field strength.

The magnetic separation of a mineral requires that the physical structure be considered, the bond between particles being broken by crushing or grinding so that the individual grains are free to respond to the magnetic attraction. The close sizing of the material is essential to efficient separation.

The magnetic separators employed for this class of work may be classified in two ways. The first class would comprise those machines which deliver one magnetic product and a tailings, the second machines which deliver a number of different magnetic products and a tailings.

The second classification would divide the machines according to the way in which the feed is presented to the magnets. Firstly, the gravity type wherein the material falls past the magnet system under the action of gravity ; the magnets being constructed in various forms ranging from drums to highly magnetised rollers. The second group would comprise those wherein the magnetics are lifted from the feed against the action of gravity. Usually the feed passes over the magnet pole on a feed belt and the magnetics are drawn up to a revolving disc, having shaped teeth cut in the underface ; an alternative to the disc is the use of a thin cross feed belt under the upper stationary pole which enables the magnetics to be taken clear of the main feed belt.

The magnetic field in the working gap must possess a steep gradient to enable the feebly magnetic particles to be lifted or deflected, according to the type of machine, and this is invariably done by employing a very high average field strength in the gap and then concentrating the field by making one pole flat, while the opposite pole has V-shaped teeth of such an included angle as to give the greatest concentration.

It is not always appreciated that a body placed in a magnetic field does not carry a magnetic flux, as would be expected, based on the field strength and the permeability of the material. This is due to the fact that the body, when magnetised, tends to demagnetise the field producing the magnetisation.

Consider the case of a particle of magnetic material travelling on a feed belt through the magnetic field. Terming the field across the particle H^1, the external field as H, and the field due to the particle as H^{11}

$$\text{then } H^1 = H - H^{11}$$

In the case of a spherical particle,

$$H^1 = \frac{3\,\rho^1}{2\,\rho^1 + \rho}\,H$$

where ρ = permeability of particle and
ρ^1 = permeability of surrounding fluid, in this case air = I.
ρ = I + $4\,\pi\,k$, where I = intensity of magnetisation and

$$k = \text{susceptibility and is equal to } \frac{\rho - \mathrm{I}}{4\,\pi}$$

The actual force on a particle is proportional to its density and magnetic moment, not as the permeability. The force of attraction on a particle of very low permeability varies as

$$(\rho - \mathrm{I})\ H, \quad \text{or,} \quad 4\,\pi\,k\,H.$$

Examples of this class of machine are illustrated. The first, Fig. 4, is the Rapidity separator, which delivers one magnetic product and a tailings. It should be noted that the two feed belts both handle the same material and deliver the same magnetics and tailings, the division being made for mechanical reasons. The extracted magnetics are lifted up to the highly magnetised disc and cling thereto until the disc revolves to a point where the carried magnetics are in a position equidistant from each pole and subject to zero attractive force ; due to the effect of remanence, it is usual to provide some form of brush to remove fine particles from the disc.

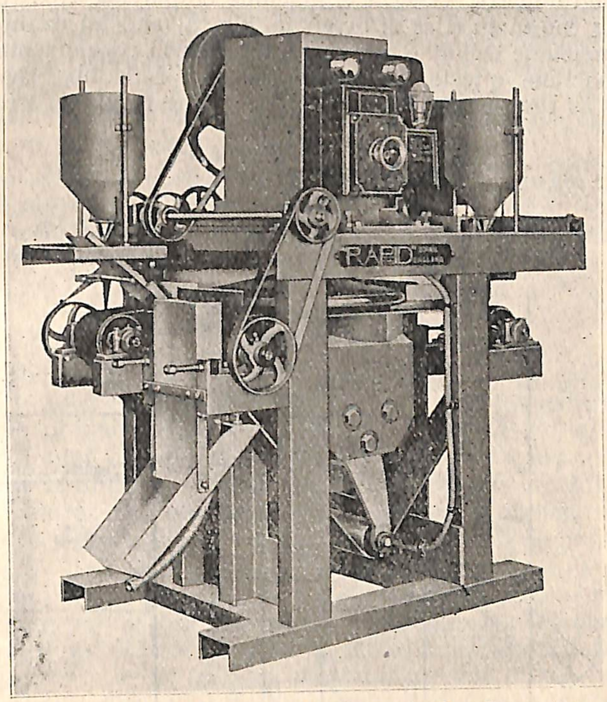

Fig. 4.—"Rapidity" Feebly Magnetic Ore Separator.
The Rapid Magnetting Machine Coy.

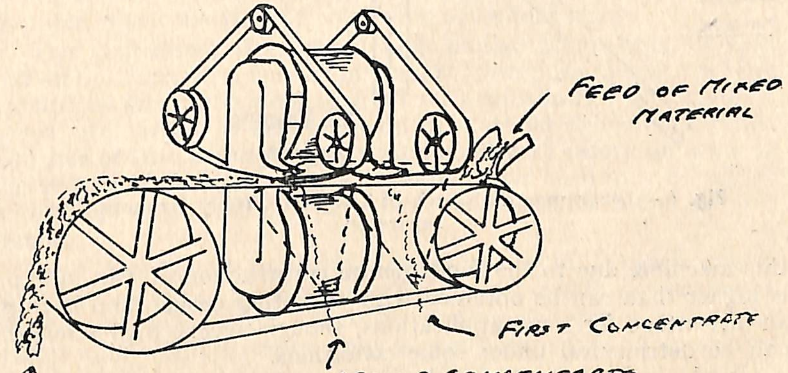

Fig. 5.—Diagrammatic Arrangement of Cross Belt Feebly Magnetic Ore Separator.

A diagrammatic view of a machine employing cross belts for removing the magnetics is given in Fig. 5, and an example of a gravity machine in Fig. 6, which shows the roll type machine. This latter machine effects the separation by deflecting the falling particles as they pass over the rollers. The magnetic strength of this machine, due to the fundamental construction of the airgap, is higher than can be obtained with any other design, and is thus an advantage for some applications, though a very high strength can be detrimental under some conditions.

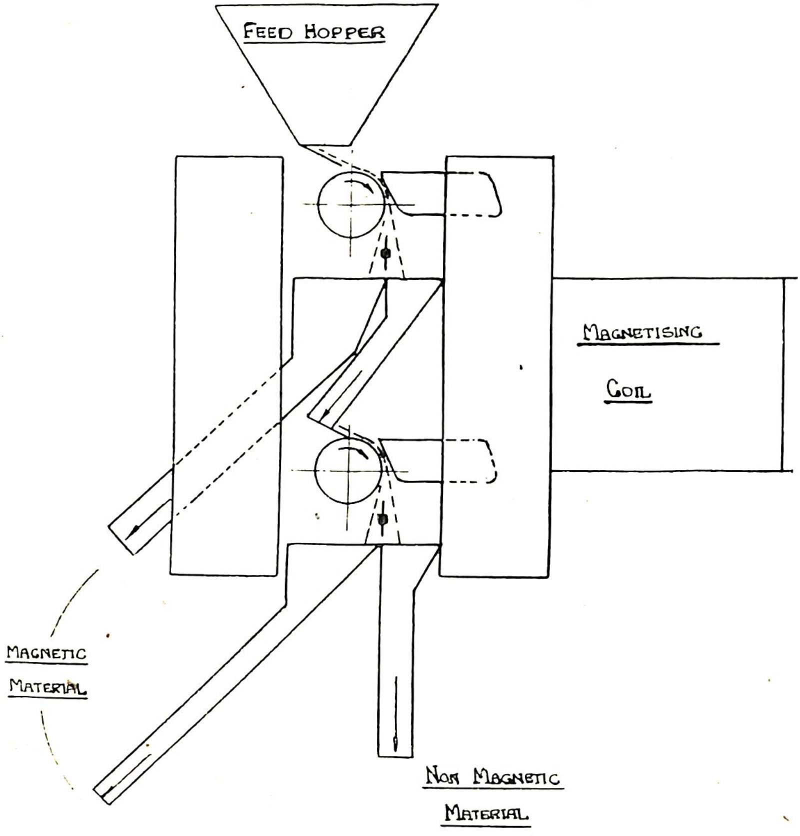

Fig. 6.—Diagrammatic Sketch of Two Roll Feebly Magnetic Ore Separator.

In the case of the feed belt machines, it may be thought that by increasing the belt speed a far higher output could be obtained. This is not so, for the following reason. The upward acceleration given to a particle, that is lifting from the main feed, is dependent on the field gradient and the susceptibility of the particle ; this acceleration controls the time taken to rise and the belt speed must be such that the time taken for the particle to travel on the belt the length of the magnet pole is less than the time taken for the accelerating particle to reach the magnet disc, or else it will fall back on to the belt.

The lifting types of separator give a cleaner separation than the gravity types, as there is less risk of a magnetic particle, especially of lower S.G. than the non-magnetics, entraining a non-magnetic particle and delivering it into the magnetics chute.

MAGNETIC SEPARATORS

Magnetic separation is a process which is being applied to industry to an ever-increasing extent. New products are introduced, the production of which would be carried out under the greatest difficulty if the magnetic separator were not available. Under war conditions, when a source of supply is cut off, as for example rubber, the position would be most precarious without the assistance of the separator for the purpose of reclamation.

Generally speaking, the use of magnetic separators can be confined to four main purposes—firstly, the protection of crushing, grinding and pulverising plant, etc., from damage ; secondly, the use for purifying a product, that is, the removal of very fine iron which may have a detrimental effect on the use of the product ; thirdly, reclamation, that is the removal of ferrous material to enable the main material to be re-used, as, for example, scrap metals and foundry sand ; and fourthly, the use for salvage, that is, the collection of the ferrous material for its own value, as, for example, the collection of tins from household refuse.

The protection of crushing and similar plant from damage caused by tramp iron is most important, tramp iron being the term applied to stray iron ranging from nuts and bolts, stray hammer heads, etc., which is always found in material delivered in bulk. The size of tramp iron that can be passed with safety depends on the setting of the machine ; a sledge hammer head may be passed with safety by a crusher, while a tack may cause much damage to a grinder.

In a number of industries, the presence of a spark caused through tramp iron getting in the feed may cause fire or explosion. Flour mills have been burnt down through sparks caused by tramp iron. Similar risks exist in many industries ranging from iceing sugar to explosives.

The purification of a product is applicable in many ways. Small nails enter tea when tea chests are opened ; fine scale from the process pans and pipes is found in sugar and is detrimental from the sales point of view. A very large number of products are separated magnetically, ranging from paints to foundry sand and from foodstuffs to pottery.

The reclamation of materials, especially under war conditions, is one of the largest fields for the magnetic separator. In these cases the magnetic material is removed, so that the remainder of the material handled is good for re-use.

Non-ferrous metals are used in very large quantities in engineering work and the resultant scrap from machining operations becomes contaminated with iron and steel in both large and fine form. The re-use of the material by remelting would, therefore, not be allowable, due to the iron content often running to a high percentage and being unacceptable if the ingot metal is made to strict specification. The urgent need for rubber has resulted in the collection of considerable quantities of scrap, some in the form of old tyres and soles, and containing pieces of wire which must be removed before processing.

The collection of scrap paper in the form of magazines, etc., calls for separators to remove the small binding clips, paper fasteners, etc. The reclaiming of foundry sand has always required a separator to remove the very large amount of ferrous material contained in the knocked-out sand. These are only a few examples of the reclamation of materials which require separating before re-use.

The last use, namely salvage, is really the reverse of the previous application. In this case the material, for example household refuse, is separated to obtain the old tins and scrap iron and not to save the refuse, though the clinker resulting from the burning of the refuse is used for road-making and other purposes and must be free of iron.

The principle of magnetic separation is very old, the first patent in this country for a magnetic separator being granted to Fullerton in 1742, while the separation of feebly magnetic ores appears to have been first done on a laboratory scale by Dalesse in 1848.

The above remarks indicate the general use of magnetic separators, but the manufacturers of this class of apparatus are always investigating new fields of application ; as an example may be quoted, the attempt at the removal of sulphur from boiler coal, especially in pulverised form. Sulphur usually exists in coal in the form of pyrities, and in the ordinary way is not susceptible to magnetic influence. Sulphur is diamagnetic, and in ores is roasted to produce the oxides which are strongly magnetic.

Genuine pyrites are too feebly magnetic to be separated magnetically, but it is not considered that all the sulphur is in this condition. Experimental work in the removal of sulphur from coke has been found to be much more favourable than for raw coal.

Magnetic separators for general use may be classified into two main groups—those that automatically discharge any ferrous material removed from the feed, and those that have to be shut down at intervals for the tramp iron to be removed from the magnet. The first class comprises magnetic drums and pulleys, while the second class includes suspended magnets and chutes.

The great advantage of the magnetic pulley (Fig. 7) is that it can be installed in a plant at any future date without structural alterations, always providing that the existing head pulley is of such diameter that the equivalent pulley will have sufficient magnetic attraction. In the case of long conveyors, the head pulley is usually of sufficient diameter to obtain the required traction for the belt.

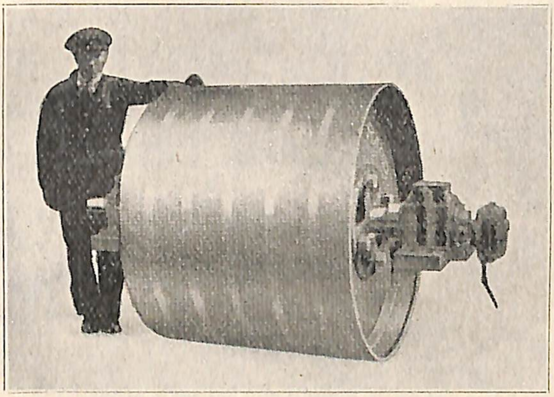

Fig. 7.—Large Electro Magnetic Separating Pulley.
Rapid Magnetting Machine Coy.

A magnetic pulley consists of a number of units, according to the length of the pulley, assembled on a shaft, each unit consisting of a circular core carrying the magnetising bobbin and having a circular flange at each end of the core, producing a circular field around the outer face. The method of operation is that any tramp iron travelling along the belt will be held against the magnetised pulley face and carried round to a point where the force of gravity is greater than the magnetic attraction, when the iron will fall off clear of the feed. It is preferable that the belt be level for a short distance on the underside to facilitate the iron leaving.

The magnetic drum follows closely on the lines of the magnetic pulley, with the exception that in this case the magnetic system is only adjacent to the drum cover on the front half of the drum and is fixed to a stationary shaft. The drum cover is fixed to two end flanges rotating on the shaft, the cover and flanges forming a hollow drum. The method of removing the iron and releasing it is exactly the same as in the case of the pulley.

An outstanding improvement in this class of separator is the provision of a patented system of forced ventilation which, by allowing much higher rating, results in greatly increased field strengths and better separation.

The writer has designed a magnetic drum, three feet diameter and six feet long, weighing $7\frac{1}{2}$ tons, the overall length being nearly eleven feet. This is by far the largest magnetic separator built in the world. (Fig. 8).

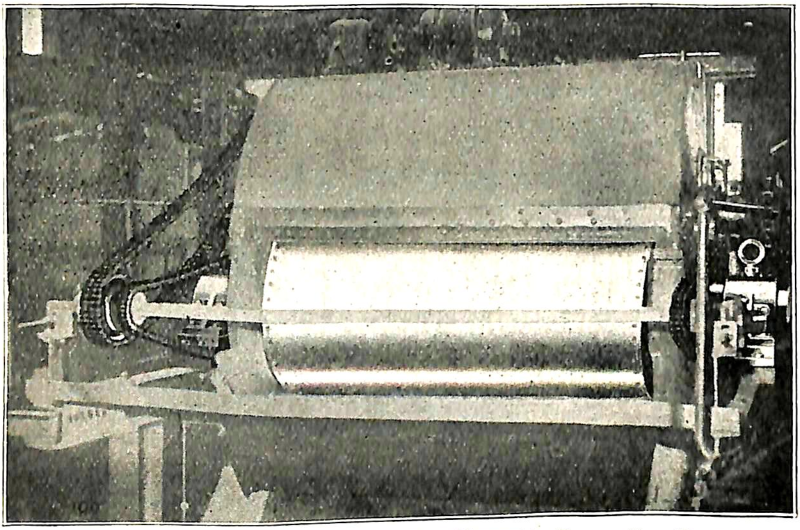

Fig. 8.—The World's Largest Electro Magnetic Separating Drum. Installed at Head of Six Feet Wide Bagasse Conveyor.

Rapid Magnetting Machine Coy.

The suspension magnet usually employed is the circular type mentioned under lifting magnets, and is employed for conveyors handling rock, coal and similar materials. The magnet can be placed with the face parallel to the conveying strand of the conveyor, though it is difficult to see what advantage this arrangement has over a good magnetic pulley, as the magnet has to operate by lifting the iron against the action of gravity, whereas the pulley has the action of gravity to assist it.

The main pull from a circular magnet being from the centre pole, it is necessary that the diameter be nearly as great as the feed width, making the magnet both large and expensive.

The magnet parallel to the belt is not of outstanding performance, but this is entirely different when the magnet is located

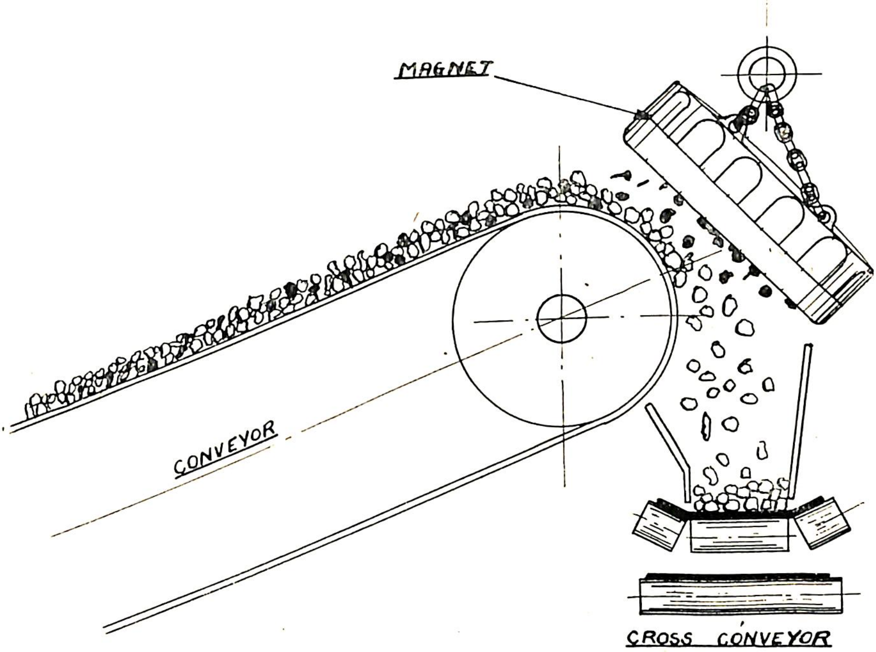

Fig. 9.—Arrangement of Suspension Magnet at Head of Conveyor for Extracting Tramp Iron from Feed.

at the end of the belt across the head pulley, as shown in Fig. 9. It may be thought that the magnet will magnetise the steel head pulley when in this position, but if this magnet is located in the correct position there is no risk of the tramp iron holding on to the pulley. The final position of the magnet is dependent on the size of the magnet, magnet size of lumps and the rate of feed.

A popular form of magnet for use with conveyors in the U.S.A. is a special form of bi-polar magnet, which is capable of operating across very large gaps; in this case, however, the magnet must be placed across the top belt strand.

The chute magnet is made in a very large variety of types. In general it consists of a trough having a number of bars placed at right angles to the direction of the feed, the bars being magnetised by coils placed below the bars. A suitable incline has to be given to allow the feed to fall by gravity and for this reason the chute is usually termed the waterfall type.

The chute is also employed for the removal of fine iron from powders, which will not flow down a stationary chute, and in these cases the magnet bar trough is reciprocated at high-speed in the direction of feed.

The separation of liquids is performed in a separator similar to the chute, but as the extracted iron is usually only a few microns in size, it is usual to incorporate an element having many points which are easily highly magnetised.

The materials usually handled in wet form include paper pulp, that is, waste paper when it has been pulped down with water; pottery slip, that is, the clay mixture when in the form of a thick creamy liquid; suds and cutting oils, and at the present time, explosives such as guncotton.

LIFTING MAGNETS

This class of magnet is probably the best known to the general public, due to its spectacular performance, especially if the magnet is of large size. Apart from magnets specially designed for a specific purpose, there are three main types, the circular, rectangular and the bipolar, each having its specific field of application.

The circular magnet is employed in far larger numbers than any other type, being ideal for steel-works, scrap-yards and other locations where large quantities of loose material have to be handled. A pile of material can be handled by a crane and magnet employing one man, at a rate which could be only equalled by the employment of large gangs of labourers. The writer has seen trucks of pig iron unloaded at the rate of 110 tons an hour. In the case of furnace charging, the magnet will do as much work as six men.

The circular magnet is available from diameters as low as 9 ins. for lifting ingots, up to the 52 and 62 inch diameters, which are standards in steelworks. The weight of the latter size is 3½ tons.

The windings of the smaller, and sometimes the larger, sizes are made up of asbestos-covered wire on a metal bobbin. In the case of the larger steelworks magnets employed for 24 hours a day, the use of strip windings is favoured owing to the greater reliability and heat-resisting capacity of the materials employed. Strip windings consist of bare copper strip interleaved with impregnated asbestos, tape and insulated throughout with heat-resisting micanite, all mechanically clamped in position.

All magnets used outdoors, irrespective of the type, are filled with a high melting point bituminous compound, with a view to preventing the ingress of moisture and to prevent sweating due to alternate heating and cooling.

Due to the heavy conditions of working for magnets, provision is made for excessive wear; for instance, the pole shoes are given a liberal allowance for wear, lifting chains are made several times the working load to allow for the heavy wear which takes place between the links.

The rectangular magnet (Fig. 10) is the shape the name implies, and is invariably employed for handling plates and sheets. Should

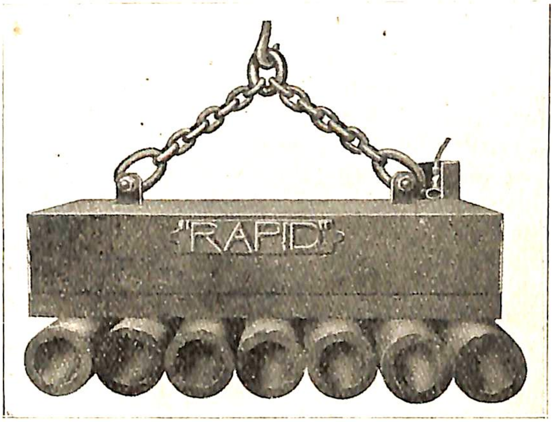

Fig. 10.—Rectangular Lifting Magnet Handling Six Inch Shell Forgings. Rapid Magnetting Machine Coy.

the plate be very long, two or three magnets are used on a common suspension beam. Due to the shape of the coil, it is usual to use asbestos-covered wire wound on a former.

The risk of mechanical damage to the coils being remote, the coil cover is of non-magnetic material, often cast, whereas in the circular magnet a non-magnetic manganese steel bumping plate is used.

The lifting capacity is dependent on the thickness of the plate. Either one thick plate or a number of thinner ones can be handled, the total thickness of the thinner ones being considerably less than the one thick plate. An experienced operator will lift a number of plates and by skilful use of the controller drop them all except one.

The bipolar magnet finds its chief use in the handling of long sections, such as rails and pipes, one or more magnets being suspended from a spreader beam in a similar manner to the rectangular magnets. Standard rails up to 60 ft. long can be lifted with two magnets. The construction consists of two main poles joined by a horizontal core on which is located the magnetising coil in a suitable protective casing.

Special lifting magnets are made in a variety of forms according to the work to be handled. Steel is magnetic up to the critical point, of the order of 720°C. and magnets arranged for high temperature lifting must have the poles arranged so as to prevent excessive heat, either by radiation or conduction, from reaching the coil. Other magnets, having specially designed poles, are built for handling one product only, such as coils of strip.

The use of magnets is not limited to use above ground. With suitable design they can be used underwater. For example, the writer has designed special units for holding drilling tools to the sides of sunken ships during salvage operations ; all requirements as regards head of water can be met.

The control gear for lifting magnets, especially of the larger sizes, calls for close attention, due to the highly inductive nature of the coil and risk of insulation breakdown due to excessive voltage rise. The sectional area of the core of a large magnet is large, and the coil, especially if wound for 500 volts, comprises many turns.

The voltage induced by the collapse of the field when switching off is high and in most cases a demagnetising current is applied in the reverse direction to drop the load quickly. This causes a much more rapid collapse of the field and consequently higher induced voltage. The voltage induced is proportional to the rate of change of the current.

The provision of suitable discharge resistances and heavy arcing contacts and blowouts to the contactors is most essential. A 200-amp. contactor is required for a 50-amp. magnet to enable it to stand up to a cycle of operations which will often exceed 60 lifts an hour.

MAGNETIC MOULDING MACHINES

The basic operating mechanism of this machine is the solenoid, and it is interesting to note that the solenoids used are far larger than those used for any other application, including oil-switch operating units.

These moulding machines follow general modern foundry practice and are made in a number of different types according to the work to be handled. A great advantage of this type from the installation point of view, is the fact that the machine is entirely self contained, unlike pneumatic or hydraulic operated machines, which require extra plant with piping to the moulding machines. The magnetic machine requires a pit for providing access to parts below the floor, but only channels are required for supporting the weight.

It will be noted that the power consumption while the machine is operating is high, but the actual total power consumed is very low ; for example, 100 moulds, $20 \times 12 \times 3\frac{1}{2}$, can be made for a consumption of one unit ; this is because the power is applied for two seconds only per operation.

The machines are designed to operate with sand pressures of 35 and 50 lbs. per sq. in. for box and boxless moulding respectively. The pressure is obtained from the centrally-mounted solenoid, as shown in Fig. 11, in the case of machines handling boxes up to 600 sq. inch area, and in the case of larger machines two or four sole-

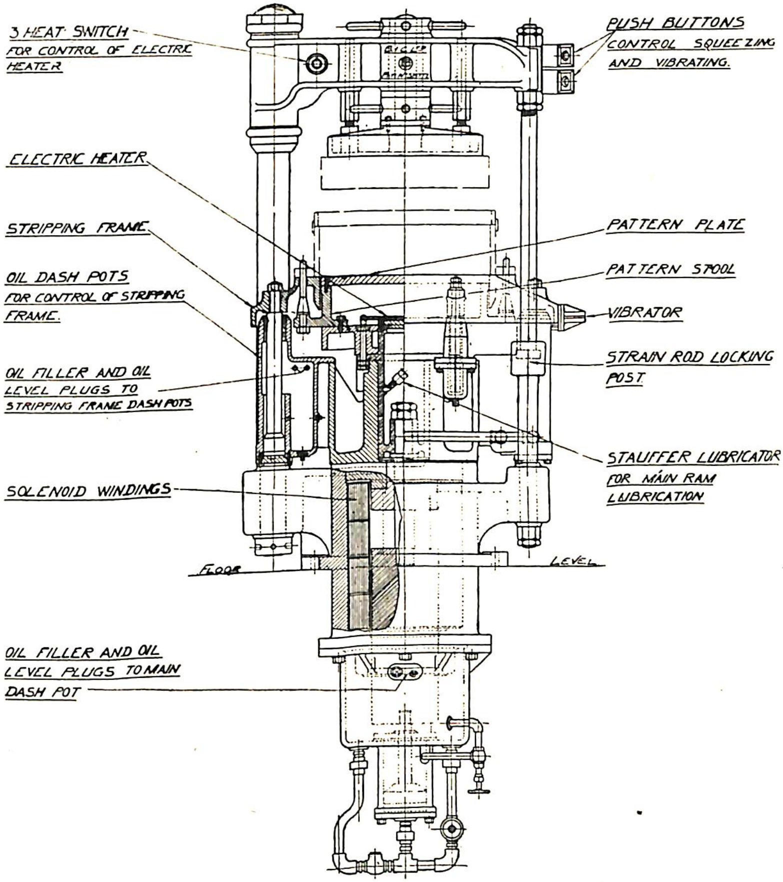
3 HEAT SWITCH FOR CONTROL OF ELECTRIC HEATER
ELECTRIC HEATER
STRIPPING FRAME
OIL DASH POTS FOR CONTROL OF STRIPPING FRAME.
OIL FILLER AND OIL LEVEL PLUGS TO STRIPPING FRAME DASH POTS
SOLENOID WINDINGS
FLOOR LEVEL
OIL FILLER AND OIL LEVEL PLUGS TO MAIN DASH POT
PUSH BUTTONS CONTROL SQUEEZING AND VIBRATING.
PATTERN PLATE
PATTERN STOOL
VIBRATOR
STRAIN ROD LOCKING POST
STAUFFER LUBRICATOR FOR MAIN RAM LUBRICATION

Fig. 11.—Cross Sectional Arrangement of Magnetic Moulding Machine. British Insulated Cables Ltd.

noids are employed, the solenoids being synchronised to obtain equal division of load and equal pressure all over the mould.

It will be noted from the sectional view that the magnetic circuit surrounding the solenoid is part of the actual machine frame made of cast iron. The coils are wound in sections, enabling easy replacement to be made. The power consumption is as much as 26 kW. in the larger sizes and requires the use of copper strip for winding.

If a battery of, say, 12 machines were operated simultaneously, the heavy power consumption would call for a most expensive power supply rectifier to convert to the required D.C. A sequence interlocking relay is provided in such cases, permitting only one machine to be operated at a time. As an operation takes only two seconds, the question of delaying work while one machine functions does not apply.

If D.C. supply is not available, it is obtained from A.C. by the mercury arc rectifier. This has a high efficiency and minimum no-load losses. The rating of the rectifier should permit momentary overloads of the order of 100% of the normal continuous rating.

MAGNETIC FATIGUE TESTING

Modern engineering work, such as aircraft, calls for the most complete knowledge of the materials used in construction, especially where high stresses are employed, due to weight restriction. Many tests, such as tensile, hardness and impact, are easily and quickly made, but a design based on tensile strength on a steady load test may fail if alternating stresses are applied, the part failing due to stress reversal setting up fatigue.

The correct working stress for a given material under these conditions can only be obtained with alternating stresses applied to the sample. The test will usually be carried out to the order of ten million reversals, the number of samples being six to eight.

A number of fatigue testers are available, but suffer from the disadvantage that a set of tests takes a considerable time to carry out. The magnetic model enables tests with the sample to be carried out at the rate of 17,000 reversals per minute, that is one million an hour.

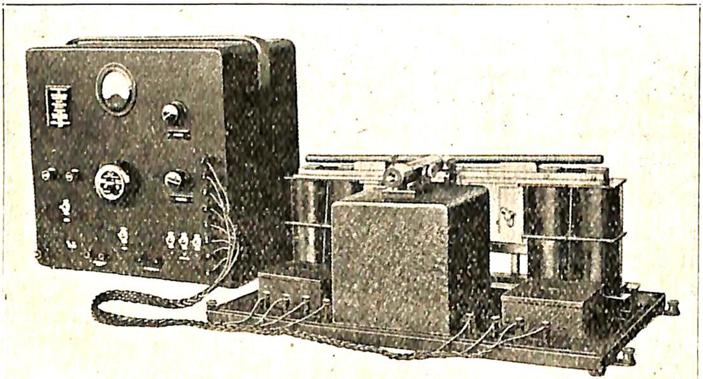

Fig. 12.—Electromagnetic Fatigue Testing Apparatus.
Salford Electrical Instruments Ltd.

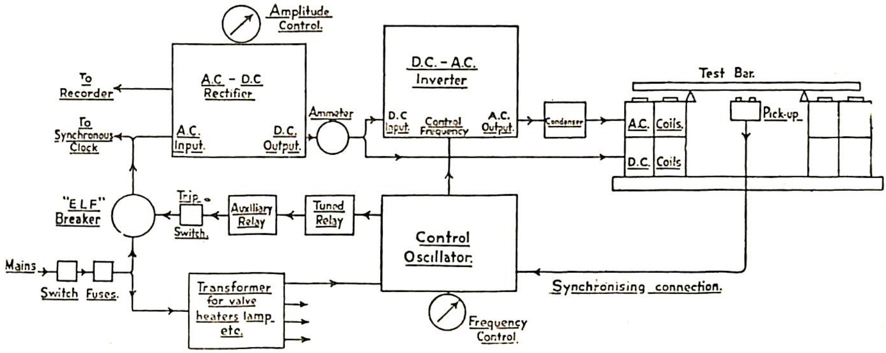

Fig. 13.—Schematic Diagram of Electromagnetic Fatigue Tester.

The apparatus (Figs. 12 and 13) consists of the test bar, the standard being $\frac{1}{2}$-in. diameter by 18-ins. long. Other sections and also non-magnetic material can be tested by suitable adjustments. The bar is vibrated at each end by a set of coils, D.C. coils providing the polarisation and A.C. coils the vibration. Supporting rubber blocks are placed under the nodes, which for the standard bar are spaced ·522 × the bar length apart. The two ends vibrate up and down above the magnets, their amplitude being 1·645 times that of the centre of the bar where the maximum bending moment occurs.

The curvature of the bar, and hence the stress, may be calculated from measurement of the vibration amplitude, a microscope reading to ·0002 ins. being supplied. Therefore when starting a test, the required amplitude is calculated from the formula :

$$\text{Amplitude ins.} = \frac{99{,}320 \times \text{stress (tons sq. in.)}}{\text{Young's modulus (lbs. sq. in.)}}$$

and the polarising current set to give this amplitude.

The value of Young's modulus can also be easily obtained by measuring the frequency of the vibrating bar, for the standard bar,

$$E = 388 \times \text{weight of bar lbs.} \times \text{cycles per second}^2$$

The A.C. for the coils is obtained from an inverter, and the frequency of this is controlled by a control oscillator, in turn guided by the voltage induced in a small pick-up coil mounted below the centre of the specimen which synchronises the control oscillator.

A tuned relay is provided which is set to operate at five cycles per sec. below the bar frequency ; on the formation of a crack the natural frequency of the bar will fall slightly and the subsequent operation of the tuned relay closes an auxiliary relay, shutting down the apparatus.

The testing of non-magnetic material is carried out by placing steel clips on the bar to provide a means of attraction by the magnets ; the formulae have to be corrected, but the results are easily obtained.

The recorder, when used, is driven by a synchronous motor through special gearing, which gives a time base which is logarithmic from 40 seconds to 3 days. If a number of testers are employed, they can all record on the same apparatus by using separate pens.

MAGNETIC CRACK DETECTION

The examination of finished machined parts for flaws, cracks and similar defects is now standard practice, thus avoiding sending defective parts to the assembly line. Many components, such as parts for aircraft engines, locomotives, etc., are subject to an alternating stress during operation, and the slightest crack, however minute and possibly invisible to the eye, will cause a zone of concentrated stress which may fail suddenly while in service. This method of testing can only be applied to ferrous parts, and to a limited extent, welded work.

The basic principle on which this method of testing works is very simple and depends on the well-known fact that in a magnetic material, the susceptibility of a flaw is very much lower than that of the sound metal. Cracks, slag inclusions and blowholes act as an airgap in the path of the magnetic flux, providing that the flux is caused to flow in a direction substantially at right angles to the principal plane of the defect. Obviously, the success of the method is dependent on the flux being directed in the required manner and at the correct density.

A defect in the path of the flux will cause it to bend round the fault and will result in an external distortion of the field, which in the case of a small surface defect will be purely local, while in the case of a blowhole or large slag inclusion, a larger area of distortion will be caused. The area of distortion can be increased by strengthening the field, though this must be watched if the part being tested has different cross-sectional areas along its length.

The question of flux density is most important. If the value is too low, then the lines broken by the crack will be diverted through a sound part of the article and no external distortion will be shown. On the other hand, if the density is too high, there will be considerable distortion over the whole work, preventing accurate examination from taking place. It is essential, therefore, that means be provided for regulating the strength of the applied field.

Two main methods of magnetising are employed, the first being to pass a low voltage heavy current through the article in a longitudinal direction. A suitable step-down transformer is used, the

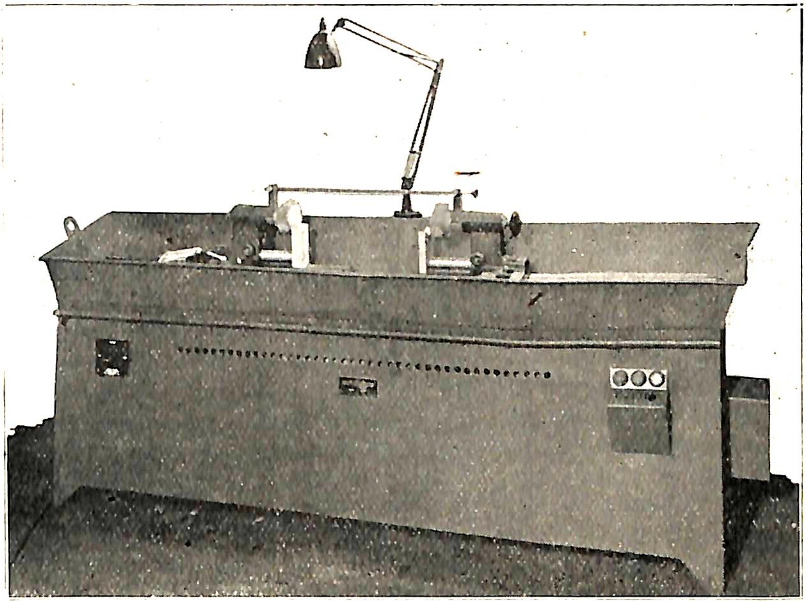

Fig. 14.—Universal Model Magnetic Crack Detection Machine. Fel-Electric Ltd.

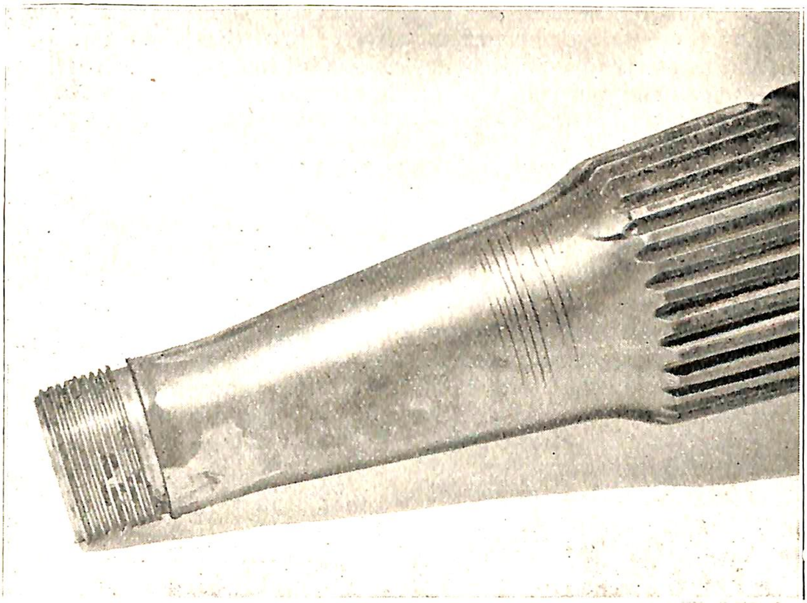

Fig. 15.—Example of Small Cracks Magnetically Detected.

secondary being provided with quick release clamps to connect with the work. The second method is to lay the work across two magnet poles, these poles being connected by a core carrying a magnetising coil, the work completing the magnetic circuit. The work is magnetised to an extent controlled by the current value employed in the magnetising coil. In the case of work which is susceptible to cracks in the longitudinal, as well as transverse direction, a combination of both methods may have to be employed.

The actual detection of the crack is carried out by spraying the work, while in the magnetised condition, with the special detecting fluid consisting of very finely divided particles of magnetic material in a suitable carrier. The particles are usually chemically produced to obtain the required degree of fineness. A suitable carrier is either a light oil or spirit ; while the spirit is very useful for some work, the high evaporation loss is troublesome.

The fine particles in the fluid will adhere to the edges of the crack and clearly show as a distinct line on the surface of the work. The fluid is usually black, but as this does not show clearly on work such as forgings, other colours are now available and avoid the need to sandblast or aluminium spray the parts before testing.

In the case of crack testers employing a magnetic system in place of a step-down transformer, care must be taken in opening the circuit of the magnetising coil to avoid excessive voltage rise, due to the highly inductive nature of the circuit. The potentiometer control permits very satisfactory demagnetisation of the work. It is found in the case of axles, shafts and similar parts, unless they are properly demagnetised after testing, that there is a probability of excessive wear being caused by fine magnetic particles sticking to the journals and causing abrasion.

PERMANENT MAGNETS

This subject covers a very wide range, and it is only proposed to mention a special magnet which was built for research purposes and which is claimed to be the largest permanent magnet in the world.

Experimental researches utilising magnetic fields for the deflection of radioactive particles often require a magnetic field which will remain constant within one part in a thousand for extended periods of time. The electromagnet is incapable of giving this accuracy without considerable complication of apparatus. Potentiometer control would have to be utilised and the current checked at intervals of less than one minute ; even then, the field strength would only be of an average value.

The magnet illustrated in Fig. 16 was built for use in beta ray

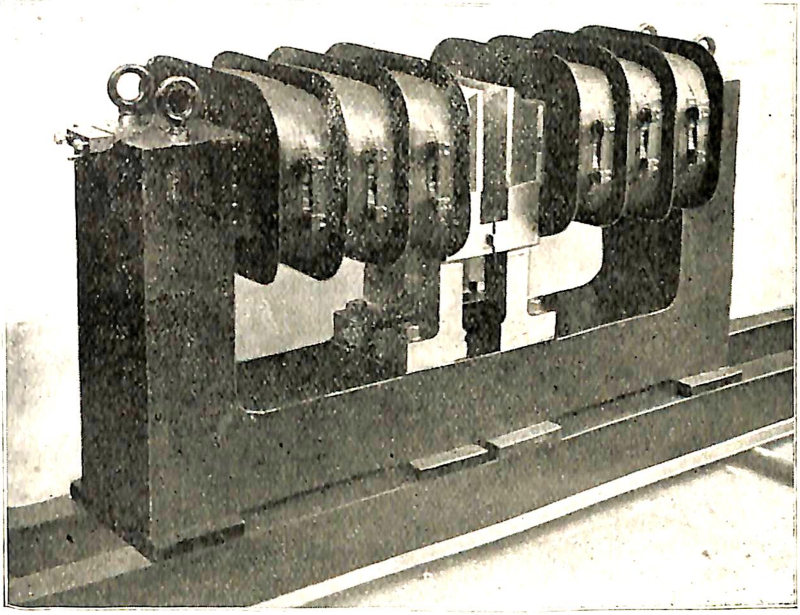

Fig. 16.—Large Permanent Magnet with Self-Contained Magnetising Coils.

Edgar Allen & Co.

spectroscopy, the permanent magnet being adopted for the reasons stated. The cost was considerably more than an equivalent electro-magnet, due to the fact that 500 lbs. of 35% cobalt steel was built into the unit.

The magnet is equipped with magnetising coils to enable any required field strength to be obtained. In operation to obtain a specific field strength, the magnet is demagnetised by passing a current through the field coils in the reverse direction. The current is then again reversed and the magnets magnetised with a value of current taken from the calibration curve, only a few minutes being required to obtain a field strength within 2-3% of that required.

The overall length of the magnet is 4 ft. 5 ins., the height 2 feet, the total weight with the magnetising coils being 2400 lbs. Extended experiments have shown that the field will remain constant within one part in two thousand for at least 4½ days. The field is obtainable over a gap of 5½ cms. when employing pole shoes having an area of 500 sq. cms.

THE ECHO DEPTH RECORDER

In the introduction, some of the phenomena associated with the magnetisation of a material were mentioned, and it was stated that some materials alter their length. It is this property, termed magnetostriction, that is utilised in the echo depth recorder.

The magnetostrictive effect is present to an appreciable amount in a number of materials. With iron, for instance, the length increases when in a low power field, and as the strength is increased the change stops and the length decreases. Cobalt shows the same effect but in a reverse manner, the length decreasing in a weak field. Nickel, however, contracts irrespective of the field strength. The alteration in length for all these materials is most minute, a 20-inch nickel rod contracting one-thousandth of an inch.

Investigations into this property show that if the magnetising field were alternating, and of such a frequency that it matched the natural frequency of the rod, resonance would occur and movements build up which are far in excess of those produced by direct current fields alone.

The frequencies used in the echo-sounding device are high, since it is necessary to employ a short rod about 5 ins. long, whose natural frequency, when vibrating in a longitudinal direction, is of the order of 20,000 cycles per second. Frequencies of this order are termed supersonic and are inaudible to the human ear. This fact is an advantage, as it prevents any interference with audible frequencies set up by the boat, such as propeller noises or waves striking the sides. Further, it is possible to obtain a very sharp beam of transmitted energy to direct to the sea bottom by the use of a reflector of reasonable size.

The accuracy of the soundings is dependent on the determination of the velocity of sound in sea water, and it is found that the value of ·0024 seconds per fathom from sending the signal to its return, does not vary appreciably in different parts of the world.

The sound transmission beam has an included angle of 30 degrees and so the diameter of the cone at the sea bottom will increase as the depth increases. The reflected beam also has an included angle of the same amount, and so it is impossible for the boat to move out of the beam before the signal returns. As an example, a vessel moving at 30 knots and taking soundings at 100 fathoms will have only moved 11 feet before the signal returns after a time interval of the order of a quarter second.

This method of measurement is also applicable to the determination of the height of aircraft. As a fighter travels at approximately half the speed of sound, the height registered is not a vertical measurement, but an angular one, which has to be corrected when the speed of the aircraft is known.

An echo depth projector consists of a laminated nickel core surrounded by a magnetic circuit of high permeability, but non-magnetostrictive material. The ends of the core are the actual working surfaces from which the sound waves are projected to the water from conical air-spaced reflectors. Each projector is mounted in a steel tank filled with water, to obtain efficient transmission of energy. The projectors are usually fitted above holes cut in the hull.

The receiver operates in a similar manner, but reversed. The mechanical motion given to the core by the returning sound waves produces a minute E.M.F. in the winding, which is then greatly amplified. To obtain the maximum sensitivity the core is polarised by a D.C. winding.

The short duration signals required are obtained by charging a bank of condensers and discharging them through the magnetising coil. This equipment is mounted close to the projector, the amplified signal being transmitted to the recorder, which is usually mounted on the bridge.

The receiving recorder merely serves to indicate the time interval from sending the signal to the moment of its return.

HIGH POWER MAGNETS

The most spectacular type of magnet as regards dimensions, weight and power consumption, are those used in physical research laboratories. The requirements of field intensity and the volume over which this field intensity is required, will vary for each application and consequently these magnets have assumed many different forms.

The flux densities required are in many cases very high, but in the case of the largest magnets the aim has not been to obtain the highest figure possible, but to obtain the largest volume over which a constant high strength can be obtained.

The air gap dimensions are determined by the purpose of the research ; in some cases a cylindrical volume is needed, while other magnets will have the air gap in the form of an annular ring.

The largest magnets of this type constructed, excluding the cyclotron mentioned later, are the magnets for the French Academy of Science, Uppsala University and Leyden University. The French magnet is the heaviest, but the Uppsala magnet is by far the most powerful, due to the correct magnetic design.

The French magnet is illustrated in Fig. 17, and it will be noted that it consists of the two pole pieces carrying the magnetising coils, each pole being mounted on a block coupled by a massive external yoke to the opposite block. The airgap between the poles can be adjusted by a motor-operated screw gear, while the inner pole adjustment is by a hand-operated gear.

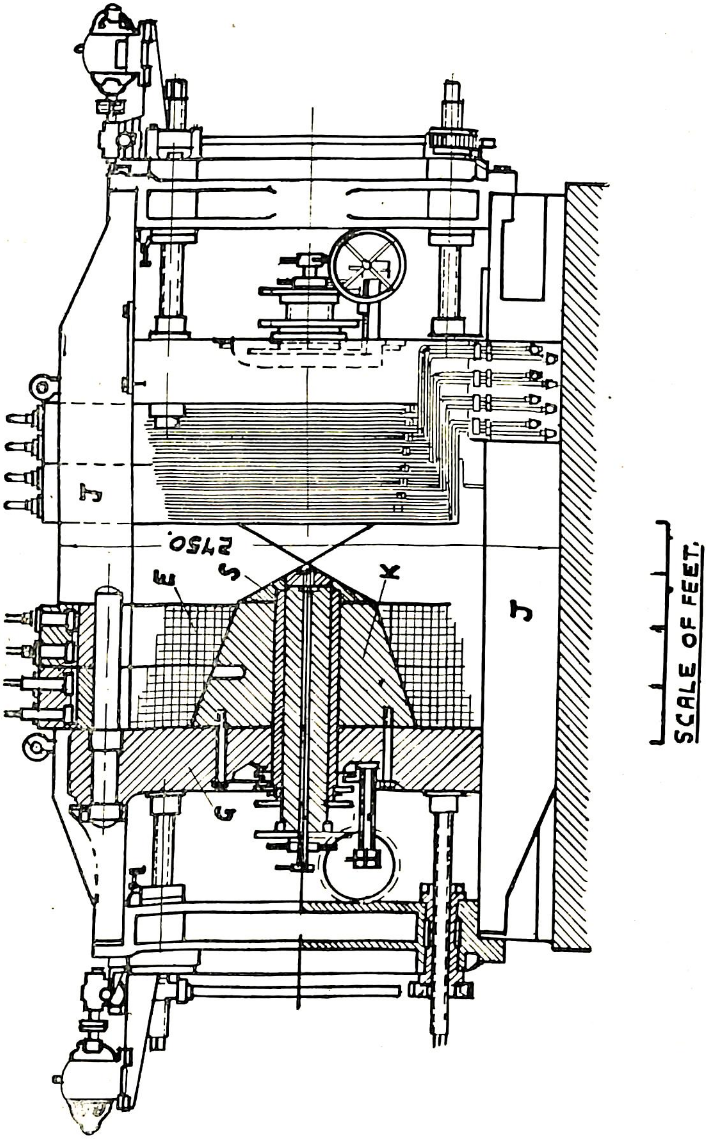

Fig. 17.—Magnet at the French Academy of Science.

The total weight is 120 tons, and the power consumption 94 kW., giving a flux density of 20,000 lines per sq. cm. in the air gap. The yoke weighs 50 tons and has a cross-sectional area of 2500 sq. ins., the upper and lower ends of the yoke being joined by two castings weighing a further 6 tons each. The largest diameter of the pole core is 48 ins., with the inner sliding core 14 ins. diameter, the completed pole being mounted on a 16-in. plate weighing 15 tons.

A point of interest with all these magnets is that the length of airgap plus the two-pole tips is very small compared with the total length of the magnetic circuit, yet they demand 90% of the total magnetising force obtained from the coils.

The Uppsala magnet is the latest and is of different construction. Here the main body is a cylindrical casting weighing 20 tons ; the pole cores are carried on end blocks, one of which is bolted to the main body, while the other is arranged to slide, piston fashion, inside the main shell. The cores are 23 ins. diameter at the small end and taper to 44 ins. diameter at the larger end. A pole and block weigh 5 tons.

The coils, as is usual in this type of magnet, are water-cooled to permit the dissipation of the large amount of heat ; for ease of winding, a rectangular conductor is used, having a central hole for the cooling water. The total weight of the coils is 4 tons, and the maximum operating current 1667 amps. at 84 volts, the coils giving 500,000 ampere turns.

The gap between the pole shoes is adjusted by means of a motor geared down to three operating screws ; the maximum load on the screws, due to the magnetic attraction, is 60 tons.

A similar type of magnet is employed at the London University on research work on cosmic rays. The airgap of 15 cms. is exceptionally long, but the field strength of 12,000 lines per sq. cm. is comparatively low. An air-cooled coil, rated at 25 kW., is employed.

The large airgap of this magnet enables some of the properties of intense fields to be illustrated. A hollow aluminium sphere, when placed in the field, floats slowly downwards, due to the eddy current damping. Similarly, the greatest effort is required to push a copper bar through the fields.

THE CYCLOTRON

This apparatus has been mentioned a good deal in the press under descriptions of atom-smashing experiments. Technically, the correct name is a "Magnetic resonançe accelerator," and it is used to produce high-speed atomic particles, being highly effective in producing the very energetic particles needed to disrupt the nuclei of the heavier elements.

The cyclotron was developed by Professor Lawrence of California as a means of overcoming the previous difficulties in obtaining high-speed particles. Previous to this time the means employed was by the use of extremely high voltages, but this has a limitation, due to the difficulty of producing an evacuated tube to stand up to voltages in excess of a million. This is overcome to some extent in the electrostatic generator of Van de Graff.

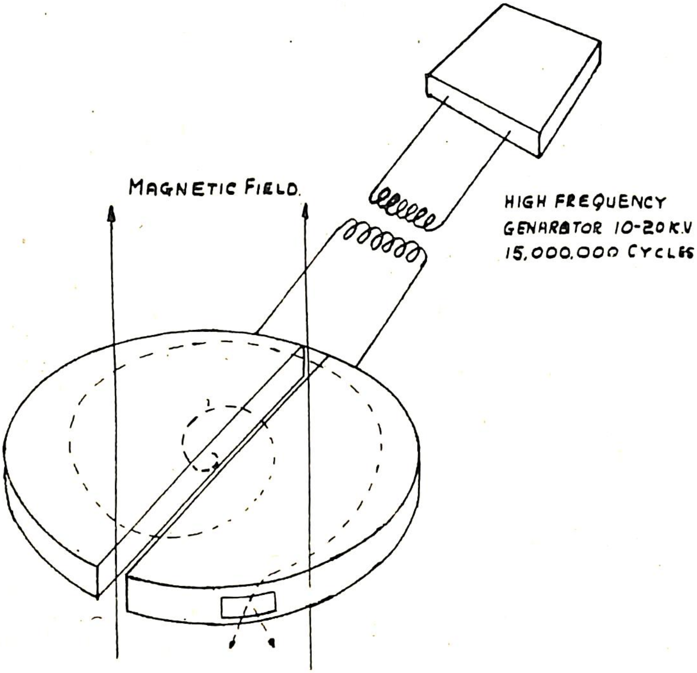

Fig. 18.

The construction of the apparatus is shown diagrammatically in Fig. 18. Two D-shaped hollow electrodes of semi-circular shape are placed in the field of a powerful electromagnet. A spiral filament, heated electrically, is placed in the centre of the electrode system. A high-frequency generator of 15 maga-cycles per second is connected across the gap between the two halves of the electrodes giving an alternating field at this point of 10-20,000 volts. The electrode system is evacuated and filled with hydrogen gas at a pressure of 1/1000 mm.

The heated spiral emits electrons and the hydrogen is dissociated. The hydrogen nuclei, termed protons, are accelerated by the electric field across the gap, while the magnetic field causes them to move in a circular orbit at constant angular velocity. The speed is such that a complete circuit must be made during the time taken for the electric field to complete one cycle.

Each time a proton crosses the gap it is accelerated, but as the angular velocity remains constant, the radius must be increased and so 50 to 400 revolutions may be made inside the casing before the proton leaves the chamber through a thin aluminium window to strike the target which will be made of the metal which it is desired to transmute.

These magnets have been made in very large sizes. A large unit at the Birmingham University has magnet dimensions of 12 ft. 3 ins. high, 15 ft. 7 ins. long, and 8 ft. wide, the pole piece being 6 ft. in diameter and parallel to a tolerance of + or – ·002 ins., the weight of the steel alone being 230 tons.

A 184-ins. cyclotron is stated to be under construction in America, and this giant among magnets is stated to be 30 ft. high by 56 ft. long, the weight of steel being 3700 tons and the copper windings a further 300 tons, 400 kW. being required for energising. A special building has already been completed, of circular shape, 160 ft. diameter and 81 ft. high. A 30-ton crane revolves around a central pivot on the cyclotron frame.

THE PRODUCTION OF INTENSE MAGNETIC FIELDS

The experimental determination of many properties of paramagnetic and diamagnetic materials requires the application of an intense field to obtain satisfactory results. For example, susceptibility measurements of many materials require a high sensitivity of measurement and an intense field, due to the fact that the value may be only a millionth of that of a ferro-magnetic material. The change of resistance of a material under a magnetic field may be only 1% in a comparatively weak field ; under the most intense fields this change may be as much as 30%.

Intense fields are produced by three methods, the use of electromagnets, as previously mentioned, or the use of air-cored coils, and lastly, the use of transient fields. The last two methods are considered here, due to the serious limitations with the electromagnet.

The use of air-cored coils is naturally open to serious limitations through heating, when operating with powers of several hundred kilowatt, and the highest field strengths for continuous fields are of the order of 4×10^4 ampere turns per cm., which compares with the figure of 6×10^4 ampere turns per cm. for iron-cored magnets.

The previous limitations have been overcome by Kapitzas, through the development of methods of employing transient fields of the order of 0·01 seconds, and he has obtained fields of the order of $2{\cdot}5 \times 10^6$ amp. turns per cm. for a total volume of 3 c.c.

Two methods have been employed; firstly, the use of special batteries which, when short-circuited through a coil, have a resistance equal to the battery resistance allowed power of up to 1000 kW to be obtained for the time period mentioned. The coils were wound of copper strip, interleaved with silk, and had an internal diameter of 2-3 cms.

A development of this method has resulted in the use of a special low reactance single-phase generator having a special exciting winding arranged in such a manner that a flat-topped wave is given. The generator employed is a 2000 kW. unit, but so arranged that when short circuited it will deliver 220,000 kW.; again, when employed with a coil of equal resistance, the power available is reduced to 50,000 kW.

The possible field strengths available with this unit are one million gauss, though the limit so far has been of the order of 300,000 gauss. The arrangement is strictly confined to the short-time period, due to the high temperature rises.

The construction of the coils was one of great difficulty, due to the forces tending to burst them. The experiments with battery-operated coils allowed the use of copper, but the stresses obtained when operating with the generator made the employment of high tensile cadmium copper reinforced with steel bands essential. The shape of the coils was such that the resultant pressure on the conductor is equal to a uniform hydrostatic pressure. The tension on a coil at full power exceeds 140 tons, and when considering this figure it must be remembered that the coils are of small size.

The alternator is mounted on a substantial foundation block, but when short-circuited such a violent shock is transmitted through the ground that the test apparatus has to be mounted 25 yards away, so that the test is finished before the ground shock reaches the apparatus.

All records are made photographically by an oscillograph. The current value, time coil is energised, etc., are taken, the falling photographic plate being released at the same time as the coil is energised by a cam switch being mounted on the alternator shaft.

Other methods of obtaining high powers for short periods, without excessive demands on the power supply, have been tried out, and, in fact, are commercially employed. Electrostatic condensers charged to a high potential are employed with the coil immersed in oil to prevent electrical breakdown between turns and for cooling purposes. This method is also employed in spot welders.

A further method is to employ an inductance. This consists of an iron core with magnetising coil and a secondary coil. In operation the magnetising coil is energised, the secondary circuit closed, and then the magnetising coil opened. The voltage induced in the magnetising coil is enormous, and as a discharge resistance or condenser across the contacts is not allowable, a multi-break switch must be used and this is a continual trouble. The power obtainable is dependent on the rate at which the magnetic field collapses; a discharge resistance allowing a circulating current to flow would greatly increase this time. As an example of the power that could be obtained, if the switch trouble could be overcome, a core about 6 ft. long by 18 ins. diameter, will give 1200 kW. The method is used commercially for magnetising permanent magnets.

An essential feature of all these tests is to know the exact value of the flux density available. In the case of the air-cored coils, this can be calculated from a knowledge of the dimensions of the coil and the current. Other methods are the use of built-in search coils in conjunction with a ballistic galvanometer. A further method is the use of a bismuth spiral which has been previously calibrated; this has the property to a large degree of changing its resistance when in magnetic field, or, finally, the method developed by Quincke of using a liquid of known susceptibility.

POWER SUPPLY

Practically all the apparatus described requires a direct current for excitation and due to the prevailing use of A.C. it is essential that this be converted. In the case of smaller apparatus, the metal rectifier or mercury types are suitable, but for large units, such as lifting magnets, etc., the use of a motor generator set is preferable.

CONCLUSION.

It is hoped that the above brief descriptions have given some idea of the scope of magnetic engineering as separate from the more common application. The work has an engineering technique equal to the other branches, and a magnet is designed mathematically like a bridge, despite the fact that a magnetic field cannot be insulated or guided where it is required, like a hydraulic medium.

BIBLIOGRAPHY.

"Magnetic Clutches," H. E. Hutter. *Mechanical World*, Dec. 1st, 1939.

"Magnetic Clutches," H. E. Hutter. *Oil Engine*, Feb., 1940.

"Magnetic Ore Separators," H. E. Hutter. *Electrician*, July 2nd, 1937.

"Magnetic Separators," H. E. Hutter. *Engineering and Boiler House Review*, Jan. and Feb., 1937.

"Magnetic Separators," H. E. Hutter. *Mine and Quarry Engineering*, Oct., 1937.

"Magnetic Separators," H. E. Hutter. *Food Manufacture*, May, 1939.

"High Power Magnetic Drums," H. E. Hutter. *Electrical Engineer*, Dec. 23rd, 1938.

"Lifting Magnets," H. E. Hutter. *Electrical Engineer*, April 3rd, 1936.

"Magnetic Crack Detection," G. B. Youngs. Charles Griffin & Co.

"Permanent Magnets," S. Evershed. *Journal I.E.E.*, 1920, p. 780.

"Echo Depth Recorder," Wood & Smith. *Journal I.E.E.*, 1935, p. 550.

"High Power Electro-Magnets," H. E. Hutter. *Electrical Engineer*, May 27th, 1938.

"The Cyclotron." *Methuen's Physical Monographs.*

"The Cyclotron." *Physical Review*, 45/608/1934.

"Production of Intense Fields," Kapitzas. *Physical Society Proceedings*, 42/425/1936.

"Production of Intense Fields," Kapitzas. *Royal Society Proceedings*, A/105/693/1924.

GENERAL BOOKS ON MAGNETISM.

"Modern Magnetism," Bates. Cambridge University Press.

"Electricity and Magnetism for Degree Students," Starling. Longmans Green.

"Magnetism and Matter," Stoner. Methuens.

"The Earth's Magnetism," Chapman. Methuens.

"Magnets," Underhill. McGraw Hill.

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